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Architectural Strategies for Low Energy House in Nanjing

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Abstract

This paper introduces the concept of low energy house (LEH) and the energy need of LEH in Europe. In accordance with the Standard of LEH in Europe, the author puts forward the energy needs for LEH in hot-summer and cold-winter region in China. As an example, a typical multi-story house in Nanjing is analyzed with different architectural strategies for LEH using Climate Surface (a software for building energy analysis), and the result shows that the most effective strategy to reduce the energy need should be improving the thermal properties of windows.

Keywords: Low energy house; Energy efficiency; Architectural Strategy

1. Introduction

In recent years, due to the rapid development of economy and the low efficiency of energy use, many cities encounter very serious consequence of energy lack, especially electricity power in south of China. Some extraordinary policies were enforced in order to solve this problem, for example, "POWER CUTOFF to Limit use" is taken as one of main management strategies. Some local governments encourage their offices raising the set-point of air-conditioner 1℃ to reduce the electricity consumption in peak power load period of hot summer and forbid turning on the air-conditioner when the exterior temperature is below 32℃. The energy consumption in buildings is becoming major part of gross energy use. It is reported that the ratio of energy in buildings is about 25% ~ 30% of gross energy use in China. With the higher requirement of living quality, more energy for better thermal environment will be needed.

In order to control the excess energy consumption in buildings and to improve the level of residence thermal comfort, some energy efficiency standards are issued. New built residential building will have to meet these standards compulsorily. So we can believe that more and more energy efficiency buildings will appear with these codes.

Compared to the low energy building standards in Europe, the energy consumption of buildings meeting codes in China are still quite high. It is necessary to further reduce the energy and improve the thermal environmental quality.

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2. Low energy houses in Europe

Low energy Houses are buildings in which a comfortable interior thermal environment can be achieved with an active heating and air-conditioning system needing low energy. For reasons of environmental protection and the comfort requirement, new regulation on low energy building is issued in Europe, especially in central Europe, e.g. Germany, Switzerland, Austria and Sweden, etc. In Germany, For example, the regulation of energy saving (Energieeinsparverordnung EnEv) prescribes a low energy house (LEH) standard, in which the building energy for heating and cooling must be below 70kWh/m^{2}a (252MJ/m^{2}a)， 30 kWh/m^{2}a to ultra low energy house (NEH) and 15 kWh/m^{2}a to Passive House[1]. In Switzerland, the Mienergie Label prescribes the heating and cooling energy need of new building mustn't exceed 42 kWh/m^{2}a (151MJ/m^{2}a).

According to the research under IEA's solar heating and cooling programme (TASK 13)[2], several state of art technical strategies should be adopted to assure so low energy need in buildings. Firstly, super-insulation of building's envelope is requried. Normally, the U-value of wall and roof should lower 0.2W/m^{2}K. Secondly, high-performance window system with adjustable exterior sun shading devices is needed. That includes low U-value(about 1.0 W/m^{2}K), high solar and light transmittance. Besides of these, The buildings need to be very airtight to reduce the infiltration loads and avoid the thermal bridge. As about HVAC systems, high efficiency heat recovery systems and ground-coupled heat exchanger are used widely. The traditional full-air HVAC system is substituted by some new heating and cooling systems, eg. Slab radiant system, chilled beams, displacement ventilation system, etc.

3. Strategies for low energy house in Nanjing

3.1 Basic climate condition of Nanjing

According to the standard of Distribution of Chinese Climate, Nanjing belongs to the Hot Summer and Cold Winter area. The monthly horizontal global radiation and average temperature are showed in Fig.1. There are almost 3-month heating season and 2-month cooling season. The heating degree-day HDD_{18} is 1967℃· d, and the cooling degree-day CDD_{26} is 175℃ · d. The outside average air temperature in heating season is about 3.0℃, and the lowest temperature in winter is about –10 ℃. In summer, the highest temperature is above 40℃, and there are about 20 days when the maximum temperature exceeds 35℃. The relative humidity keeps very high all over the year. Heavy rainfall mainly happens from the end of spring to the beginning of autumn. The prevailing wind direction is south or southeast in summer and northwest or north in winter.

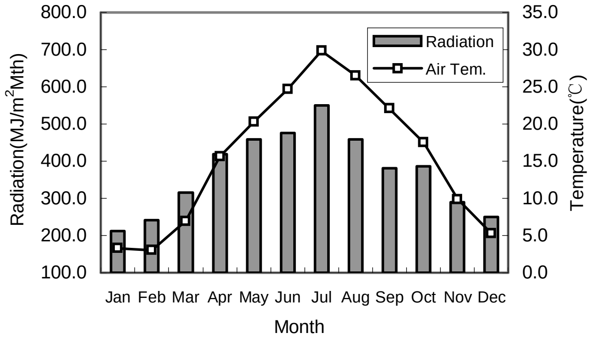

Fig.1. Horizontal Global Radiation and Average Monthly Temperature in Nanjing

3.2 Energy need limitation on new built house

One new standard about the energy efficiency building design in hot summer and cold winter Area in China was issued in 2001. According to this standard, the new residential building's energy consumption must be reduced to 50% of that of old residential buildings built before 1980's. We can deduce the total energy consumption on cooling and heating through some indexes from this standard. Table 1 shows the deducing results of total energy need for heating and cooling in buildings of several cities within hot summer and cold winter area.

It can be seen from Table 1 that the total energy consumption on house in several big cities belonging to this area is from lowest 290.4 MJ/m^{2}a in Chengdu to highest 460.4 MJ/m^{2}a in Nanjing.

Table 1. Building Energy Need Nowadays in Several Hot Summer and Cold Winter Cities in China*

City	HDD_{18}	CDD_{26}	Heating (KWh/m^{2}a)			Cooling (KWh/m^{2}a)			Total		
			Electricity	EER**	Energy	Electricity	EER	Energy	Electricity (KWh/m^{2}a)	Energy (KWh/m^{2}a)	Energy (MJ/m^{2}a)
Hefei	1825	116	34.0	1.9	64.6	20.5	2.3	47.2	54.5	111.8	402.5
Nanjing	**1967**	**175**	**37.2**	**1.9**	**70.6**	**24.9**	**2.3**	**57.3**	**62.1**	**127.9**	**460.4**
Shanghai	1691	164	31.0	1.9	58.9	24.1	2.3	55.3	55.1	114.2	411.3
Hangzhou	1647	196	30.0	1.9	57.1	26.5	2.3	61.0	56.5	118.0	424.8
Wuhan	1792	195	33.2	1.9	63.1	26.4	2.3	60.8	59.6	123.9	446.0
Changsha	1557	275	28.0	1.9	53.2	32.4	2.3	74.5	60.4	127.7	459.9
Nanchang	1468	254	26.0	1.9	49.4	30.8	2.3	70.8	56.8	120.2	432.9
Chengdu	1454	27	25.7	1.9	48.8	13.9	2.3	31.9	39.5	80.7	290.4
Chongqing	1073	241	17.2	1.9	32.7	29.8	2.3	68.6	47.0	101.3	364.6
Guilin	1139	182	18.7	1.9	35.5	25.4	2.3	58.5	44.1	94.0	338.5

* Note: The interior design temperature is from 18℃ in winter to 26℃ in summer, and air change rate is 1.0 h^{-1}.

** EER: Energy Efficiency Ratio, the values are taken from the standard.

The corresponding thermal requirement of each building's element in the standard is as Table 2.

Table 2. Thermal Requirement of Building's elements

Elements	U-value (W/m^{2}K)
Roof	1.0(high mass) or 0.8(low mass)
Wall	1.5(high mass) or 1.0(low mass)
Window	4.7(WWR*≤ 0.25) or 2.5(WWR≥ 0.3)
Door	3.0
Floor and Boundary	2.0

*WWR: Window Wall Ratio

Compared to the Standard of building energy efficiency design in hot summer and cold winter, the energy need of Mienergie Standard is only 1/3 of the energy need in Nanjing, regardless of the difference of climate and the interior thermal environment. So it is suitable that the energy need of low energy house in Nanjing is below 100~150 MJ/m^{2}a under the similar condition of interior thermal environment as Europe.

3.3 Low energy strategies

In order to reduce the energy need of buildings, the ways are always that reducing the heat loss through the opaque wall, roof, window and infiltration and getting more solar energy through window in winter, and reducing the cool loss through the opaque wall, roof, window and infiltration, and reducing the solar energy entering rooms in summer. In other words, we must raise the gain loss ratio γ value and reduce the total loss factor K in winter. In contrast, we should reduce both of the γ and K in summer. To solve such a contradictive problem, the best way is to use adjustable exterior strong sun shading device. So it is clear to building design that the strategies on low energy building will be:

A. Lowering down the U-value of opaque wall, roof and window, to reduce the heat loss in winter and the cool loss in summer. With the reduction of window's U-value, the solar energy transmittance (g-value) will also be reduced. It is benefit to reduce the energy need in summer time, and in winter, the key point is the net gain through window.

B. Reducing the infiltration. With the reduction of the energy need, the portion of the infiltration energy loss will become an important part of total energy need.

C. Adding adjustable exterior sun shading. As discussed above, it is best way to solve the contradictive problem on solar radiation between summer and winter.

4. Validity analysis to different strategies

4.1 Case study

As an example, a typical multi-story residential building in Nanjing is calculated on energy consumption with or without the strategies above using the energy analysis software Climate Surface, which is developed by Division of Building Physics in the Institute of Building Technology at Swiss Federal Technology Institute Zurich (ETHZ)[3]. It is a simple analysis tool only for heating and cooling energy need in buildings or rooms, suiting for energy analysis at early stage of building design. The change of energy needs with different strategies in buildings can display out quickly. The mathematical model of this software is based on the energy balance equation and the core is the Free-Running Temperature concept. The closer the interior Free-Running Temperature is to comfort temperature(normally from 20-26℃), the less energy for cooling and heating will be required[4-5].

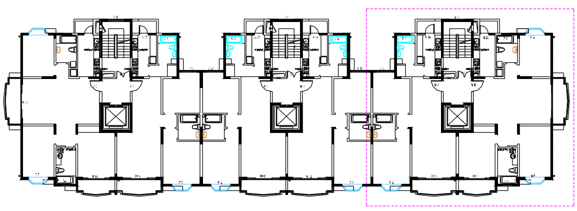

Fig.2. Standard plan of the residential building analyzed

This building can be considered as "Energy Efficiency Building" in Nanjing. The standard plan of the building is showed as Fig.2. We selected a standard unit, including two families as the analysis object. One is 3-bedroom and 1-living room (Type A) and another is 2-bedroom and 1-living room (Type B). The plan of the unit is showed as Fig.3. From Table.3 we can see the different strategies before and after improvements. And the comparison of energy need between before and after improvement can be found from Fig.4.

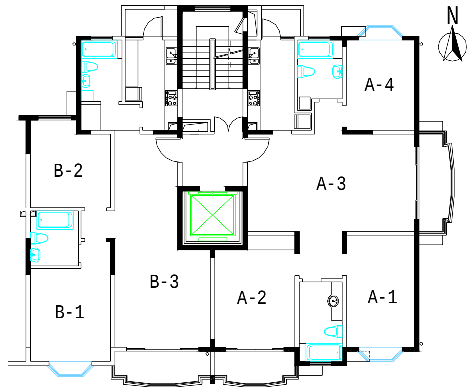

Fig.3. One Unit of the plan analyzed

Table 3. Strategies Before and After Improvements

	Wall	Window	Sun Shading	ACR* (h^{-1})
Before	240mm Hollow Brick with 20 Insulation Mortar inside, U=1.18	Single glazing U=4.7,g =0.80	Internal, Medium Shading	1.0
After	Adding 50mm polythene outside, U=0.5	Double Low-e Glazing (AR) U=1.3,g =0.64	Exterior, Adjustable Strong Shading	0.5

*ACR: Air Change Rate

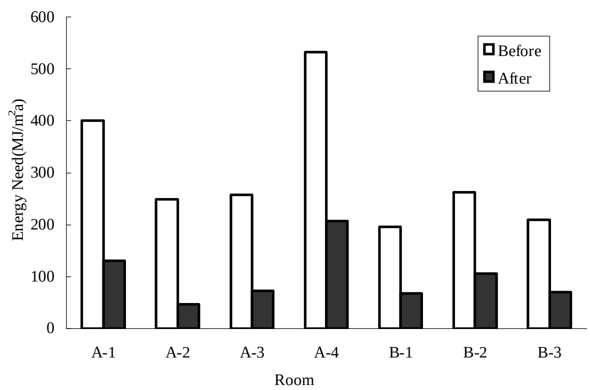

Fig.4. The Total Energy Need Comparison Between Before and After Improvements

It can be seen from Fig.4 that the total energy need for heating and cooling each room can be reduced to 100 MJ/m^{2}a after improvement strategies were used, except A-4, facing north with double exterior walls.

4.2 Effectiveness of different strategies

In order to find out the key step to low energy building, we analysed the energy need of one simple room (4m long, 5m deep and 3m high) with different strategies. These strategies are:

1: Change Medium Shading to Strong Shading,

2: Change ACR from 1 to 0.5,

3: Change Window from single glazing to super glazing (U-value=1.0W/m^{2}K/1.7(frame), g= 0.55), 4: Change U-value of Wall from 1.25 W/m^2K to 0.5 W/m^2K,

Four different direction rooms (South, East/West and North) are analysed respectively. Besides, for the reasons of sight view and fresh air ventilation, people like big windows on the wall, so change of window size as fifth option is analyzed.

5: Change WWR (Window Wall Ratio) from 40% to 80%.

0: The energy efficiency building code nowadays in hot summer and cold winter areas of China (U_{wall}=1.25W/m^2K, U_{win}=4.7W/m^2K /3(frame), g=0.8, ACR=1.0h^{-1}, Medium Shading, WWR=40%) is considered as the reference condition.

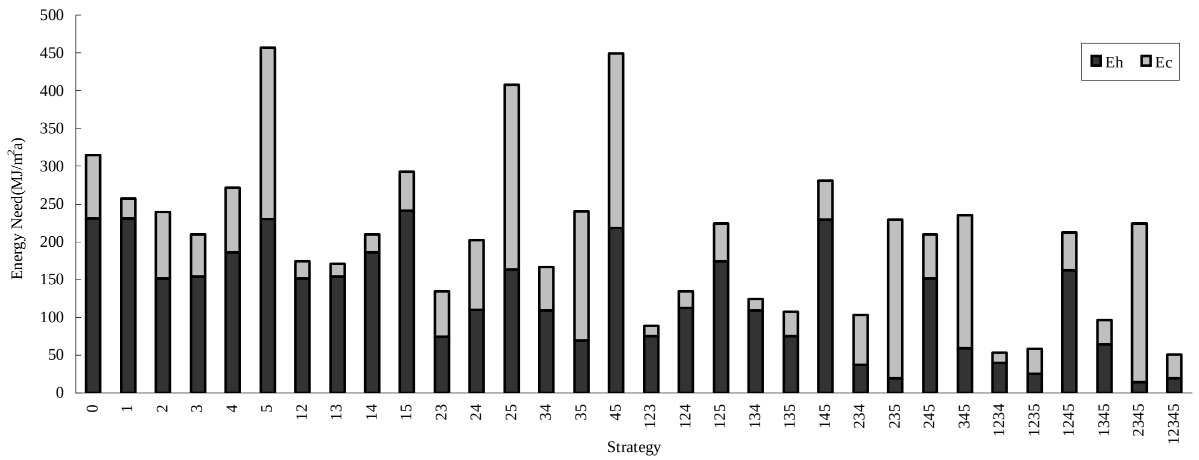

Fig.5. Different Strategies Comparison (South)

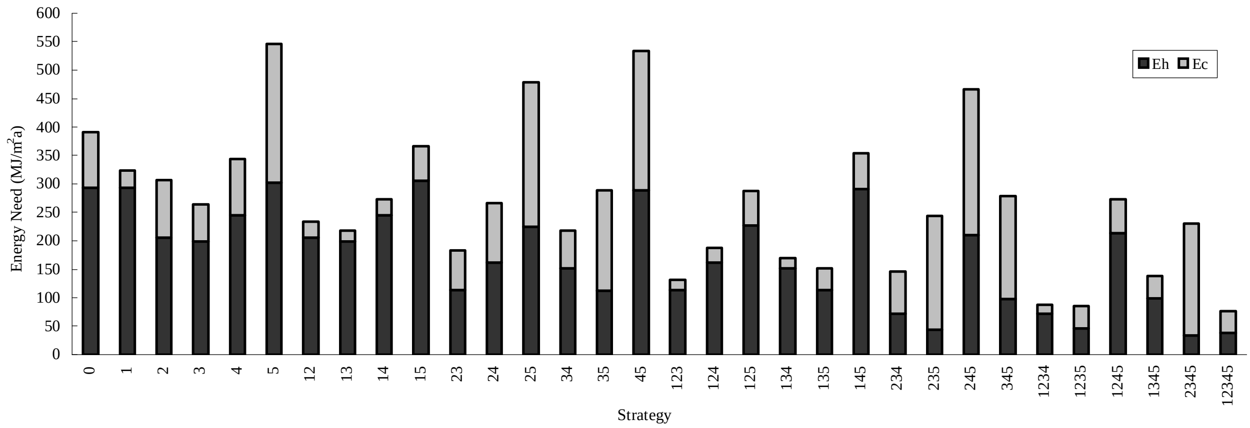

Fig.6. Different Strategies Comparison (East/West)

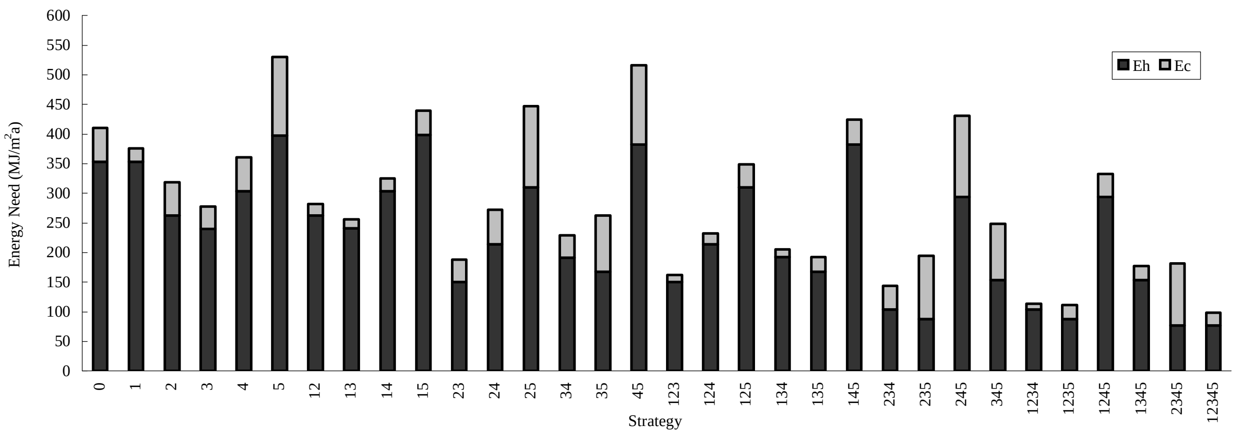

Fig.7. Different Strategies Comparison (North)

Fig.5~7 show that the most effective procedure for low energy house is **0→3→23→123→1234** in each direction. That means the first step is improving U-value of the windows from 4.7 W/m^2K of single glazing to 1.0 W/m^2K of super-glazing (double or triple glazing with low-e coating, filling with Argon or Krypton gas). Then improve the air change rate from 1.0 to $0.5h^{-1}$. Thirdly, change internal shading to exterior shading, and in the end, improve the U-value of the opaque wall from 1.25 W/m^2K to 0.5 W/m^2K. To meet the requirement of low energy building, at least three different strategies together are necessary. As to window size, we can find that enlarging the window size is not sensible under the circumstances of without strong sun shading outside and not high thermal performance of glazing.

Table 4. The Reduction of Energy Need Step by Step With Different Direction (MJ/m^2a)

	Strategies					
	0	3	23	123	1234	12345
South	315	210	134	89	53	51
North	410	278	188	162	114	99
West/ East	391	264	183	131	87	76
Avg. S&N	363	244	161	126	83.5	75

The reduction of energy need step by step effectively is showed in Table 4. The effect of building direction on energy need can be seen from it. Even under the condition of low energy house, the direction still has the effect on energy need to some extent. South facing is still the best building direction to energy saving. But as to regular shape building, for example, rectangle building, the area of wall facing north is equal to that facing south. We can also find from Table 4. that the average energy need of south and north (SN/2) is near to that of west/east direction under condition of low energy building. So we can think that the building direction of low energy building is not as important as the buildings nowadays. Architects have more freedom to choose the building direction and the size of window, not worrying about direction's effect on energy need under such condition.

5. Conclusions and Acknowledgements

In order to reach the requirement of low energy house, several architectural strategies can be taken, as analyzed above. Different Strategies have different effect on energy consumption in buildings. If we want to improve the energy need step by step effectively, the first opt will be to improve the thermal performance of window.

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